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EYE TRACKING DEVICE FOR THE MEASUREMENT OF FLIGHT PERFORMANCE IN SIMULATORS

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This paper describes the use of an eye position monitor as a research tool for evaluating the field-of-view (FOV) requirements for simulator visual systems. Traditional evaluation methods rely on the use of pilot opinion and/or objective pilot performance measures. Neither provides a direct index of the pilot's visual behavior under alternative FOV conditions. Without a direct measure, interpretation of data is often problematic. The use of an eye position monitor provides a useful adjunct to these traditional methods. The present paper describes the system architecture, initial implementation, advantages and limitations, and future application. Keywords.

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This publication is primarily a working paper. It is published solely to document work performed.

SUMMARY

Human performance data are required for the design and evaluation of flight simulators. This paper describes a data collection method which enables information to be collected on the visual behavior of pilots during flight simulation. The method described supplements traditional data collection techniques such as pilot performance measures and questionnaires.

Eye position data are collected using a head-mounted eye tracking device which incorporates infrared sensors to detect eye movement. A head-mounted camera displays the viewed scene and a superimposed eye position locator onto a video screen. A video recorder is used in conjunction with a time code generator to record the data. These data are then reduced using a computer software program that summarizes the amount of time and the number of glances for particular areas within the scene.

This data collection method was used to gather information on the field-of-view (FOV) requirements for the C-130 Weapon System Trainer at Little Rock AFB, AK. Eye position data for twelve C-130 pilots were monitored to determine the effects of a full FOV versus a limited FOV during a low-level flight and an airdrop. Pilot performance measures indicated no significant effects, but effects were significant for the eye position data. The eye position effects indicated that pilots used a different visual strategy in the two conditions. These data show how experienced pilots adapt to varying FOV configurations to maintain flight parameters. The results demonstrated the usefulness of the eye tracking system when used in conjunction with traditional data collection methods.

A second study was performed in which the eye tracking system was employed to determine FOV usage in the air-to-air environment. Twelve F-15 and F-16 instructor pilots performed air-to-air maneuvers for various training setups. Data analysis is currently underway, but initial results indicate that the system can record eye position data in the dynamic air-to-air environment.

The major advantage of the eye tracking approach is that it provides a direct measure of the pilot's eye position without restricting head movement. The absence of a fixed reference point and the labor-intensive data reduction process are two major limitations which are currently being addressed.

PREFACE

This paper was written in support of the Air Force Human Resources Laboratory's current Research and Technology Plan. The Training Technology goal for the Operations Training Division is to develop and maintain enhanced job performance and combat readiness by identifying and demonstrating cost-effective ways of developing and maintaining new skills. A specific goal is to establish aircrew Simulator Training Requirements by the application of new simulation technologies and aircrew training system designs that will permit savings by providing high quality training in cost-effective ways. The objective of this effort is to develop guidelines for visual systems and users. The present effort was conducted under Work Unit 1123-32-04, Simulator Field-of-View Requirements, by Capt Kevin W. Dixon, Principal Investigator, and assisted by 1Lt Victoria A. Rojas, 1Lt Gretchen M. Krueger, and Capt Luke Simcik.

An oral presentation of this paper was given at the 1988 American Institute of Aeronautics and Astronautics (AIAA): Flight Simulation Technologies Conference in Atlanta, Georgia by Lt Victoria A. Rojas.

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EYE TRACKING DEVICE FOR THE MEASUREMENT OF FLIGHT PERFORMANCE IN SIMULATORS

I. INTRODUCTION

The design and training effectiveness evaluation of simulator visual systems have historically depended upon data from subjective questionnaires and from objective pilot performance measures. The field-of-view (FOV) size is one important characteristic of the visual system which is often evaluated using either or both of these methods.

The questionnaire approach uses personal opinion data to evaluate characteristics of the FOV. This approach has been used in a number of studies including Newman (1983), Randle, Roscoe, and Petitt (1980), and Wiekhorst and Dixon (1987). Although this method is widely used, questionnaires suffer from being subjective in nature; also, they give no indication of the portion of the FOV being used, and they do not reveal where attention is allocated within the visual field. For example, an evaluation conducted by Goodyear-Rediffusion (O'Neal, 1984) for the F-15 Visual System asked 48 pilots to perform certain tasks in a 160° horizontal (H) X 60° vertical (V) limited-FOV F-15 simulator, rate the FOV for each task, and estimate additional FOV requirements for tasks in which the FOV was rated less than acceptable. The results of this study, based on pilot opinion, indicated that the evaluated visual system (160° H X 60° V) can substantially enhance air superiority operations training and air-to-surface operations training. Subjective evaluations performed in this manner contribute a large amount of data; however, it is difficult, based on this technique, to draw conclusions concerning the actual performance or visual behavior of the pilots.

The use of pilot performance measures (altitude, airspeed, etc.) during simulator missions can also be deceiving, because the pilot may use other means (instruments) to compensate for the lack of fidelity of the visual system. For example, Nataupsky, Waag, Weyer, McFadden, and McDowell (1979) conducted a transfer-of-training study using student pilots as subjects in the T-37 Advanced Simulator for Pilot Training (ASPT) and in the T-37 aircraft. The students learned basic contact maneuvers in one of two FOV conditions (300° H x 150° V, or 48°H x 36°V) and were evaluated on these maneuvers during their first aircraft mission. The automated performance measuring system and instructor pilot ratings were used for analysis during the simulator missions, whereas instructor ratings and individually recorded flight parameters were analyzed for the aircraft sorties. The results revealed no significant differences in performance due to FOV conditions.

The two approaches outlined in the preceding paragraphs give the researcher some idea of the pilot's impressions and of the pilot's performance, but do not allow objective determinations of the pilot's visual activity.

Continuously recording the pilot's eye position offers a data collection method to quantify pilot visual behavior during simulated flight. Eye-tracking allows direct assessment of the visual behavior of the pilot, and an indication of his attention allocation at any time during the mission. Use of an eye tracking system would have increased the understanding of why the pilots in the Goodyear-Rediffusion study rated the field of view for each task as acceptable or unacceptable. In the Nataupsky et al. study it would have provided information as to whether or not the student pilots changed their visual strategy during the smaller-FOV condition to compensate for the lack of outside visual cues.

II. SYSTEM ARCHITECTURE

After a determination was made that eye position data would fill the gap between subjective questionnaires and pilot performance measures, a suitable system to collect visual behavior data had to be found. The major factors considered were cost, ease of calibration, comfort, free head movement, and transportability.

The system chosen was a Model 210 eye movement monitor from Applied Science Laboratories. The Eye Movement Monitor employs a photoelectric sensing and processing technique to determine magnitude and direction of eye movements. Eye illumination and sensing are accomplished with infrared illumination to minimize distraction to the subject. The device is attached to a headband-mounted camera (see Figure 1).

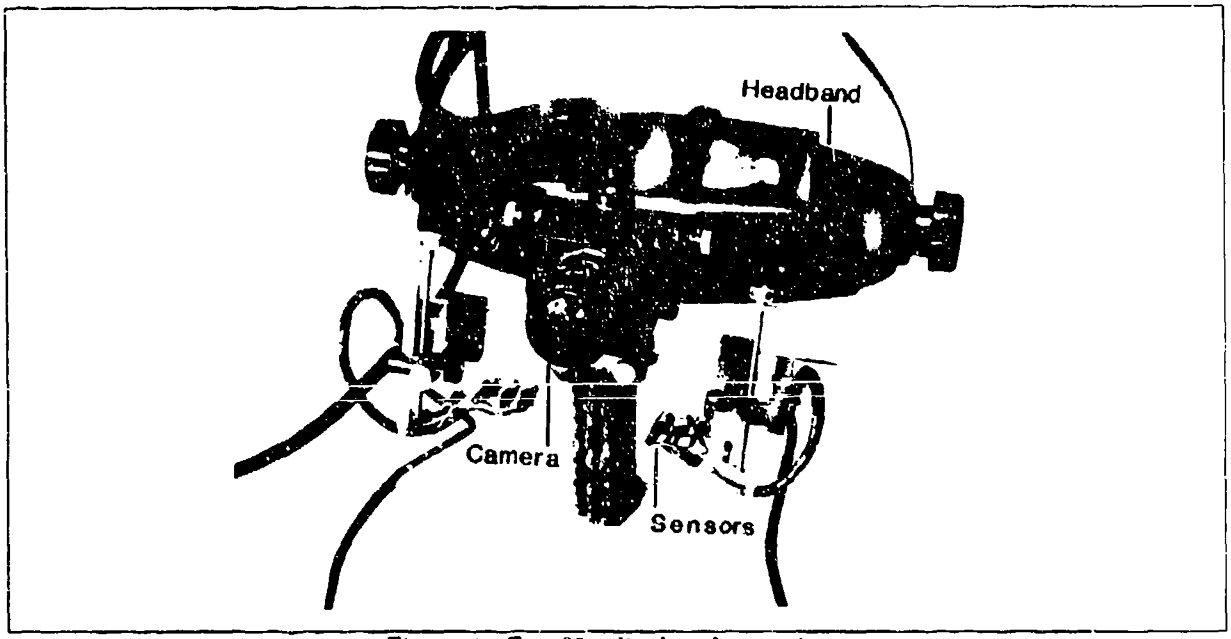

Figure 1. Eye-Monitoring Apparatus.

The instrument is capable of measuring horizontal eye movements over a range of approximately +/-15 degrees, with an accuracy of about 1 degree and a precision of better than 1/4 degree. Vertical eye movements can be measured over a range of approximately +/-15 degrees, with an accuracy of about 2 degrees and a precision of better than 1 degree (see Appendix A, System Specifications). The device can contain an instantaneous field of view of 30 degrees horizontally and vertically, and a full 360-degree field of regard.

The video fixation point capabilities of the device present either crosshairs or a cursor superimposed over a television monitor image of the scene being viewed by the pilot. The visual scene is broken up into seven areas which correspond to the seven window locations. The image is captured with a video recorder and times are coded to complete the data collection procedure. The last component of the system is Tapemaster, a video software program which is used to analyze the data. Tapemaster captures a time code from the videotape and supplies a definition of that time period with respect to the scene (window) being viewed. These data are then manipulated to provide descriptive and inferential statistics. Figure 2 is a diagram of the overall system.

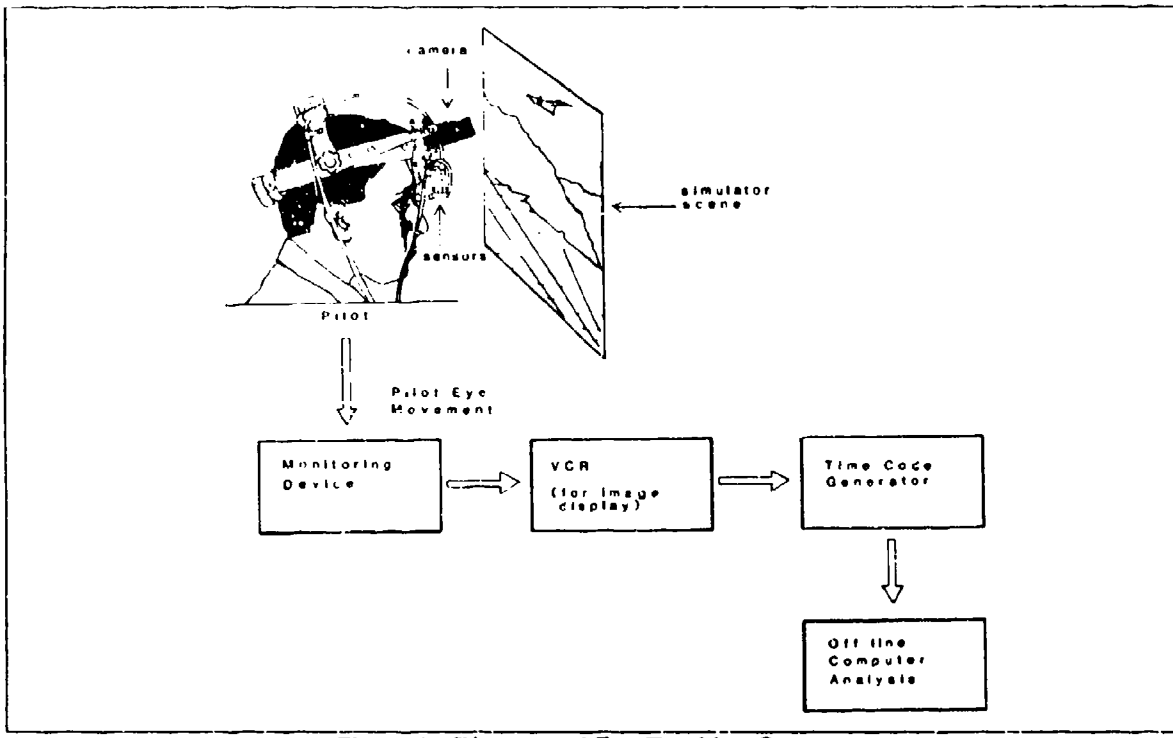

Figure 2. **Diagram of Eye Tracking System.**

III. IMPLEMENTATION

Preliminary evaluations were conducted to ensure component compatibility and proper system operation. Familiarization and proficiency training of the experimenters occurred in a static environment for the practice of setup and calibration techniques. Each experimenter required approximately 15 hours of training.

The initial field test of the system was accomplished during a C-130 Weapon System Trainer (WST) field-of-view study at Little Rock AFB, AK (Dixon, Martin, Rojas, & Hubbard, 1988). The C-130 WST is a full mission simulator which provides computer-generated imagery for out-of-the-window visual cues. The visual system produces day, dusk, and night scenes through a six-window, five-channel, color cathode-ray tube display system with infinity optics. This study investigated the effect of FOV on pilot performance for low-level flight and an airdrop in the C-130 WST. The study was performed using two different FOV configurations. The full-FOV condition incorporated all six windows to provide a visual field of 160° H by 35° V. In the limited-FOV condition, the forward four windows were used to provide a 113° H by 35° V visual field.

Two methods of data collection were used throughout the study. The first method incorporated the eye tracking system to determine whether or not pilots' visual behavior or performance is altered in the different FOV configurations. Automated pilot performance measures were also collected; these included pilot control inputs and system parameters. Twelve male C-130 pilots with a crew qualification of instructor pilot or aircraft commander served as subjects. The eye-monitoring device was worn by the pilots for the duration of the simulator test flight, which lasted approximately 25 minutes. Subjective questionnaires concerning the eye camera and headband were given to each pilot at the conclusion of the test. The pilots experienced some slight discomfort in wearing the apparatus, but reported that it did not restrain head movement or interfere with the mission.

Data from the eye position camera were encoded using a personal computer applications program. This program (Tapemaster, Comprehensive Video Supply Corp.) enabled the specification of visual area codes (area within each window, instruments, or other) for the visual field based on the video fixation point (see Figures 3, 4, and 5). "Instruments" were defined as eyes transitioning to the instrument panel, and "Other" was all fixations not related to windows or instruments. The definitions for each area were manually encoded into the computer. Once encoded, the data were transferred to the VAX 11/780 for further analysis. The variables used for analysis included: time in each window, number of glances in each window, percent of total time and glances for each window, and percent of time per glance. The results of the study showed a significant difference in visual behavior between the full- and limited-FOV conditions. This difference occurred in the percent of time spent looking at instruments, the forward window, and the left window adjacent to the forward window. During the full-FOV condition (in comparison to the limited-FOV condition), pilots spent less time looking at instruments and the forward window, but more time looking in the left peripheral window. The simulator performance measures indicated no significant differences between the two FOV conditions.

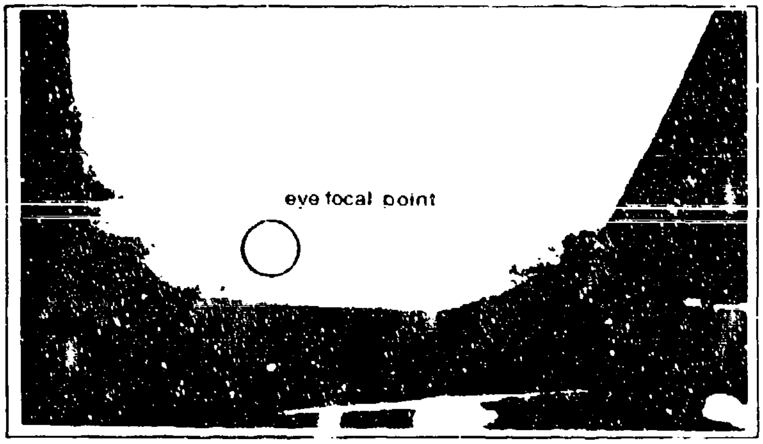

Figure 3. **Example of C-130 Eye Focal Point (Front Window).**

Figure 4. **Example of C-130 Eye Focal Point (Side Window).**

Figure 5. **Example of C-130 Eye Focal Point (Instruments).**

Experimental efforts relying solely on simulator performance measures would have concluded that there were no differences between the two FOV conditions. However, the visual behavior differences indicate that pilots are altering their visual strategy to maintain performance parameters.

A second field-of-view study was performed on the Simulator for Air-to-Air Combat (SAAC) located at Luke AFB, AZ. The objective of this study was to determine the field of view used in specific air-to-air tasks, free engagements, and mutual support operations. The SAAC consists of two F-15/F-16 interchangeable cockpits and a computer interface that allows the pilots to fight against each other or against the computer in air combat engagements. Data on number of glances in each window, time spent on instruments, number of transitions from each window, and eye position relative to target position were collected. Final data analysis is currently underway, and the results will be published at a later date. In contrast to the relative stability in the C-130 simulator, air-to-air combat maneuvers require a great deal of dynamic head movement. The incorporation of the eye tracking system in this environment was a significant step in validating system versatility and flexibility of the eye tracking device.

IV. APPLICATIONS

Results from the static C-130 WST and the dynamic F-15/F-16 tests of the eye-monitoring system indicate that it has a strong potential for both research and training environments. Proposed visual training research applications include areas in workload assessment and attention allocation. Many of these applications require initial research into visual behavior and its relationship to mental processing.

Investigations into such areas as pilot cross-check techniques are one of the many training applications possible. Based on comparisons of the visual strategy of individual pilots (focal point, time spent on each instrument, etc.), recommendations for cross-check training for inexperienced pilots could be made.

The eye tracking system could also be used for system design and evaluation. For instance, a quantitative evaluation of the visual cues used in low-level flight can be obtained with the eye tracking system. Such an evaluation will be extremely useful in order to optimize the scene content in visual displays. If incorporated into research and design methodologies, the eye tracking system could provide valuable information on the eye focal point for various tasks. The advantages of the eye tracking system make it a valuable tool that can be used alone or in conjunction with subjective and objective performance measures for valid and reliable decisions concerning visual systems.

V. LIMITATIONS

The eye tracking system does have its limitations. It only reveals the eye focal point and does not account for visual information available and processed from the visual periphery. For example, when the pilot is looking in a forward window, his periphery is also being stimulated by the information in the adjacent window. Although he does not look at the adjacent side windows as frequently as the forward windows, he receives input from these windows. The eye tracking data do not reveal this added information. Thus data interpretation is limited to information within the system's visual field only.

The absence of a fixed reference point is also a limitation that at present does not allow automation of the data acquisition and data reduction phases of the eye tracking system. A fixed reference point would allow a moving coordinate system to be superimposed over the visual field. This coordinate system would allow for automatic processing of the eye position data.

Data reduction of the recorded event is a manual process which requires approximately 2 minutes of coding for each minute of flight simulation. The coded data are then reduced with a computer software program which produces a table of descriptive statistics. The total process is very time-consuming and labor-intensive. For example, it took a team of three people 45 hours apiece to produce the descriptive statistics for a study with 600 trials.

VI. SYSTEM ENHANCEMENTS

A number of enhancements are planned for the eye tracking system. These improvements will overcome the limitations of labor-intensive data reduction and lack of a fixed reference point.

An automated eye tracking system is currently being designed by ISCAN, Inc.; the Air Force Human Resources Laboratory at Williams AFB, AZ; and the University of Dayton Research Institute. The proposed system will automatically calibrate the system to the subject's eye focal point. Synchronized infrared light-emitting diodes (LEDs) will be placed in the visual field and be referenced by an X-Y tracking system. The eye focal point data and the X-Y tracking data will be correlated to determine exact position in the field of view. Specially designed software will format the data for statistical analysis. Another enhancement is the use of a wider-angle camera to encompass more of the pilot's field of view.

The infrared LEDs and the X-Y tracker will allow for a reference point to be established for automation of the data acquisition and data reduction phases.

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